Between one and zero: noise, ghosts and plasticity.

Jane Grant, School of Art and Media, Plymouth University, Plymouth, PL48AA, UK.

E-mail: <jane.grant@plymouth.ac.uk >.

Abstract

This paper addresses two sonic artworks, *Ghost* (2011) and *Plasticity* (2012) that use models of spiking neurons to materialize endogenous and exogenous composition in relation to noise and sonic memory. In the formation of these artworks the exploration of noise is considered in the context of areas of neuroscience, cell switching and cultural theory. Noise appears to be the glue that turns the boundary or limit of the cell into a threshold, no longer indivisible. And that noise, in drawing sound into being, carries with it the root of all information implicit and explicit.

Keywords: Ghost, Plasticity, noise, neuroscience, memory, synapse, sound art.

'I'm interested in cause and effect, but only when something happens between the cause and the effect, so that the effect is not really directly related to the cause.' (Alvin Lucier) [1]

Noise is the undercurrent of matter, of information; mutable and implicit, it draws things into existence. Noise inhabits the space between the signal and its opposite. Noise is the not yet of information, the incipient structure keeping buoyant the code. The signal, stripped of its noise, is fundamentally altered and when detached from its origin cannot hold all that brought it into being. And, whilst it appears important to free the signal from the morass, perhaps the factoring out of noise is an error, particularly in living systems.

The synapse is a gap, the space between neurons. It is the site where neurotransmitters relay information from one neuron, known as presynaptic, across the synaptic cleft to the postsynaptic membrane or cell. The synapse is a place of translation, electric to chemical signals and the release of compound information into the synaptic field. It is both transmitter and receiver. The cleft of the synapse is the site of potentiality, but also of uncertainty. The translation from matter to fluid, carrying sensory information, is fascinating in that it turns away from the model of network topologies' multi-linear structure of the brain, into a fluid potentiality.

There are billions of cortical synapses in the human brain. These spaces in between are said to be one of the sites where memory is stored, both long and short term. Synapses are considered unstable as archives for memory due to their continual modification as sensory information is processed. The molecules (or neurotransmitters) in each synapse are renewed usually after five days although some are renewed at around four to five weeks. [2] Memory, however, has the potential to last for days with long-term memory lasting decades and often a lifetime. There appears to be a conflict between these scales in time, and one of the most important research questions in neuroscience is to find out how long-term memories can remain stable in what appears to be unstable circumstances.

One of the many theories of long-term memory retention is that all memories are revisited on a regular basis, perhaps in sleep. However, this theory is unlikely given the vast amounts of information presented with the potential for long-term memory imprints. Another very recent theory presented in the paper 'Long-term memory stabilized by noise-induced rehearsal', by Yi Wei and Alexei A. Koulakov, [3] proposes that memory in the synapse is given its longevity by 'implicit rehearsal'. Wei and Koulakov use the term implicit rehearsal to describe the reactivation of old or long-term memories by noises that are not explicitly reactivated or revisited. This means that an imprint of the memory could be carried by neural noise and synaptic plasticity in and of the system despite the instability of the synapses, and that this memory may be recalled for a long period of time without losing the integrity or memory image of the content or representation.

Signal and noise

Between the signal and absence is a space between something, but not nothing. The signal to noise ratio is a measure of desire and its opposite. The signal, clean, clear and crisp speaks of precision, of information transferred, understood and explicit.

Noise, however, is its abstruse partner, an undercurrent of information, not yet formed, mutable and implicit. Signals are measured, removed of noise, their code, employed and translated as information, as the opposite of nothing, or nothing structured enough to be factored in. The signal must be a singular stream, a positive. And yet it appears that noise is the underlying endogenous stimulation of the brain and many other biological systems. Sensory neurons are extremely noisy.

In the 1995 groundbreaking paper 'Stochastic resonance and the benefits of noise: from ice ages to crayfish and SQUIDs', [4] Kurt Wiesenfeld and Frank Moss discuss the presence of noise in the single neuron. One of the examples given in the paper is an experiment undertaken to discover whether there might be a benefit to the presence of noise in bio-sensory apparatus. One experiment used the mecanoreceptor hair cells of a crayfish thought to detect weak but consistent signals in the motion of water, most likely to perceive predators. In the experiment, the cells' detection of weak and most notably incoherent sig-

Fig 1 'Ghost', external image of the installation at Maksem during the Uncontainable exhibition, ISEA 2011, Istanbul. Microphones placed outside of the octagonal building pick up live sounds from the street and reconfigure them through the neuronal system. © Jane Grant. Image by Jane Grant

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nals was greatly enhanced by noise coupled with stochastic resonance [SR]. The authors report that SR may act as a threshold device in cell membranes responding to external influences 'randomly switching between open and closed states in response to thermal fluctuations' [5]. 'SR is a nonlinear cooperative effect in which a weak periodic stimulus entrains large-scale environmental fluctuations, with the result that the periodic component is greatly enhanced" [6].

In his book 'Parables for the Virtual', Brian Massumi [2006] discusses Wiesenfeld and Moss's paper:

> 'Stochastic resonance, which replaces linear causality with near-relational concepts involving "noise" (chaotic indeterminacy of signal), interactive "amplification", "threshold," and global systemic "modulation," has implications far beyond acoustics. It has particular significance for brain science, where it adds a level of non linear causality functioning *on the level of a single neuron*, even prior to the consideration of the collective behaviour of populations of cells' [7].

In the effort to understand the intricacies of the workings of the human brain, large-scale networks are often employed, however we see here that the single neuron can generate its own noise in relation to its external environment. These findings have profound implications with respect to the folding in of the exogenous with the endogenous through noise. 'Scientists often reconcile the stochastic and the deterministic by appealing to the statistics of large numbers, thus diminishing the importance of any one molecule in particular' [8].

The paper 'Nature, Nurture, or Chance: Stochastic gene expression and its consequences,' by Arjun Raj and Alexander van Oudenaarden, [9] presents a study of noise, cell switching, and fluctuation in single and small group studies of cells. In one section of the paper the authors discuss a study in which small groups of cells commit a proportion of their population to stochastically anticipate the arrival of food sources [10]. This is a neater way of detecting food and a viable and probable alternative to a situation in which cells firstly directly sense food in their environment and only then activate their metabolic network. The former strategy shows that 'stochastic switching is a viable alternative to sensing and that it is most effective when the switching rate is closely tuned to the rate at which the environment fluctuates' [11] (or resonates), even when this strategy sacrifices the switching group to 'suboptimal' growth.

It appears that noise or stochasticity is what links the internal workings of cells, groups of cells, and the organism as a whole to its environment. By being sacrificed to fluctuate or resonate in rhythm with external influences, whether food or predators, these groups of cells become peripheral whilst still being embedded in the biological host. They are at once committed to exteriority, to exogenous noise with its own rhythms, patterns and weights. We might see this internal noise as something intangible that flows from the organism, enfolding it implicitly to the external, a random and fluid equivalent to binary determinism.

Noise and networks

'Life is a study in contrasts between randomness and determinism: from the chaos of bio-molecular interactions to the precise coordination of development, living organisms are able to resolve these two seemingly contradictory aspects of their internal workings' [12].

Noise is what Henri Bergson might claim to be a halfway place between 'the thing and its representation' [13]. Noise appears to be the glue that turns the boundaries or limit of the cell and the self into a threshold, no longer indivisible.

In relation to the single neuron, the noisy network offers up the concept of innumerable discrete clusters of stimulated cells, each resonating with its variable external counterparts and its own internal structure, a circuitous route through cause and effect. This noisy network is mutable, intangible, indeterminate. Richard Coyne describes networks as 'discursive devices,' with 'shifting authorities', and suggests that'[a] further mode of resistance to the transcendence of the network is to think of the network as an effect and not a cause' [15].

Ghosts

Between the signal and noise are the ghosts of memories resonating, coming into being, aside and between sensory information. They are implicit, felt, ripples of affect, oscillating at frequencies both endogenous and exogenous. In his book 'Becoming Beside Ourselves: The Alphabet, Ghosts and Distributed Human Being' [16] Brian Rotman proposes that contemporary technology expands what we might think of as the narrated self, an autonomous, monadic, linear body.

> 'The result is a body which, though conditional by and inseparable from its evolutionary lineage, is revealed as increasingly exogenous – made and conceived from its bio-techno-cultural environs; increasingly transparent – less privately enclosed, more publically in-

Fig 2 'Ghost' internal image of the installation at Maksem during the Uncontainable exhibition, ISEA 2011, Istanbul. Eight speakers play the reconfigured sounds combined with the 'memory embedded' sounds in the neuronal system. © Jane Grant. Image by Jane Grant

spected and surveyable through a multitude of techniques; increasingly porous – engaged in a constant flow of information and affect across its boundaries; increasingly heterotopic – an assemblage of differing processes with their own histories, dynamics and itineraries understood collectively, conceived as "a type of world full of an infinity of creatures"'[17].

The ghost transgresses boundaries, extends the self both physically and temporally, and inhabits our world alongside other less tangible places. The sonic artwork *Ghost* [18] was concerned with memory revisited, implicit and subtle. In this work a model of a small artificial cortex based on the Izhikevich spiking neuronal network model [19] was developed and connected to eight microphones and eight loud speakers. The model was 'memory embedded' in the sense that sounds had been previously implanted into the cortex. The work was premiered at ISEA in Istanbul/ Istanbul Biennial and installed in Maksem, a beautiful old building in Taksim Square. Once installed, live sounds picked up by the microphones outside of the building (the microphones were attached to the windows) stimulated artificial spiking neurons modelled in the computer to 'fire', sending small fragments of sound to the eight speakers inside the building. If the external sounds fail to reach a particular threshold, the 'memory embedded' sounds begin to be heard. Over time, the external sounds start to embed themselves into the model, gathering sensory information and sonifying both the past and the present. As I have written in another context:

> 'When these sounds fail to reach a certain threshold, the cortex will journey around its own architecture, re-visiting older, established pathways, using its 'memory' as buoyancy when external stimulus dies away. This memory is its own internal noise, its earliest and primary stimulation. These sounds will be heard as 'sonic ghosts,' a term I have used to describe internal or endogenous noise embedded in the cortex, which reoccurs when the external stimulation is low or not present in the gallery space' [20].

In this space the microphones picked up the busy sounds of traffic, sirens and the Adhan from an adjacent mosque. These sounds become fragmented, reconfigured, overlapping, a flickering sonification through the speakers of the neurons firing. External and endogenous patterns and rhythms blend the neural past with the neural present, the sonic ghosts: 'the very phenomena of emergence into presence, lingering persistence, and withdrawal' [21].

In one of my earlier papers, 'Neural Ghosts and the Focus of Attention' [22], I discuss the case in Eugene Izhikevich's models of spiking networks of neurons for which external stimulation fails to reach a particular threshold (Izhikevich, 2006). In this situation, discrete networks become a 'focus of attention' so much so that they represent the firing pattern as if the stimulation where present.

> 'Perception is never a mere contact of the mind with the object present; it is impregnated with memory-images which complete it as they interpret it. The memory-image, in its turn, partakes of 'pure memory' which it begins to materialize, and of the perception in which it tends to embody itself: regarded from the latter point of view, it might be defined as a nascent perception' [23].

'When a memory appears in consciousness, it produces on us the effect of a ghost whose mysterious apparition must be explained by special causes' [24].

The ghost is a thing without referent [25], it has no substance, it is an absence of materiality or code. The ghost is perceptually intangible; it is a thing sensed, a signifier between the image and its representation. Like noise, the ghost is both exogenous and endogenous, it is imagined internally but manifests in spaces external to the mind. In the work *Ghost*, the overlaying of the sonic memories are blended in the present. These sonic phrases are 'emergent structures' [26] formed from the older established firing groups in the context of the present.

Plasticity

Plasticity [27] is a discrete participatory sound and light artwork comprising 6 microphones and 16 speakers within one large room. This work was concerned with the sonification of spiking networks of neurons heard through the context of the human voice. The computer model runs a network of 100 artificial neurons and records the input sound made by the 'audience' into the microphones, and retriggers short sections of this sound when one of the neurons 'fires'. The neuronal network is driven by a noisy signal, keeping the system 'buoyant,' and has an additional algorithmic 'plasticity' code, which changes network connection strengths according to causal firing between the neurons, mimicking simple 'learning'. When the neurons 'fire', the corresponding LED coil also illuminates causing cascades of firing events to create a scattering of light and recorded live sound across the

Fig 3. 'Plasticity' at the onedotzero 'Adventures in Motion' Festival visitors make sounds into microphones which are re-triggered by the firings of an artificial neuronal network accompanied by flashing LED lights at firing events in the adjacent gallery space. © Jane Grant, John Matthias, Nick Ryan and Kin. Image by Avril O'Neil

speaker network. A live chorus of voices performed by The Holst Singers was fed into the work as it opened at the British Film Institute as part of onedotzero's 'Adventures in Motion' Festival. This chorus then underpinned the work, forming a sound bed over which public participation took place.

The proximity of the speaker array to the microphones afforded the participants a visual overview of the work as a whole so that they could see and hear their contribution and its effect on the instrument. This work focused specifically on the voice, and therefore microphones were placed strategically and grouped together to encourage audience participation. As the participants perform, they build emerging rhythmic structures with the software using their voices or sound.

In 1908 Bergson wrote 'A remembered sensation becomes more actual the more we dwell upon it, that the memory of the sensation is the sensation itself beginning to be'. [28] And one might make an analogy here with Izhikevich's models of spiking neurons where, deprived of external stimulation and driven by noisy currents, the model re-visits older neural pathways and clusters formed by external stimulation. These pathways correspond exactly as if the external stimulation were present. Izhikevich concludes; 'Such 'thinking' resembles 'experiencing' the stimulus.' [29].

Bi-stability, multi-stability, thresholds and vagueness

Bi- and multi-stability are ideas pertaining to the phenomena in which the human mind can hold opposing or contradictory information simultaneously. 'Perceptual bi-stability may best be understood as a means for optimising interpretations of the sensory environment' [30]. However, as Denham and Winkler state, perceptual information is often inherently ambiguous and therefore the perceptual system explores likely alternatives to 'minimise misinterpretations', [31] and this process is a result of 'the active exploration of the sensory environment'.

When thinking resembles an absent stimulus, such that the noise in the system is no longer resonating with the external stimulus, the boundary between endogenous and exogenous has been transgressed. The permeability of the boundary with its resultant signal and residual noise brings about a discontinuity of localized events. These networks are not just discrete entities but form firings, ripples in the system. Philosopher David Wood puts forward the idea that boundaries are 'time shelters', interchangeable as states, and that 'a boundary is not a thing but a cluster for the procedure of the management of otherness' [32]. 'The boundaries of shelters are essentially permeable in ways that allow interruption – invasion, infection, corruption' [33].

Where Bergson talks of the extensity of sensation, the rootedness of *all* sensations that might be located externally, he claims that space is 'no more without us than within us' [34]. This shifting interchange between internal and external, endogenous and exogenous through sensation points towards the uncertainty and transmutability of how we enfold experience, continually modifying the present in relation to noisy memory whether encrypted in the neuronal network or the body: 'On the biological level, it is the margin of undecidability accompanying every perception, which is one with a perception's transmissibility from one sense to another' [35].

The signal stripped of its noise becomes linear, binary, hermetically sealed from its noisy origin. This has proved very useful in engineering and many sciences, however as technologies and engineering develop, more complex systems need noise to carry information. The re-introduction of noise is interesting; stochastic resonance has recently been developed in tiny computer chips to allow the signal its buoyancy, the noisy counterpart no longer stripped away from the integrity of the system. This 'non-linear causality', [36] that Massumi speaks of when discussing stochastic resonance, signifies the beauty and complexity of systems, the peaks and flow of information, of things above, through and beside, resolving itself in intensities both implicit and explicit.

In his discussion in which he describes what experiencing might be Massumi invokes William James' analogy as "drops" of experience, Massumi says,

> 'At the limit, what appears isn't just a drop or a pool but a whole ocean, with calm stretches and turbulence, ripplings that cancel each other out and others that combine and amplify, with crests and troughs, killer surf-breaks and gentle lappings at the shores of other situations' [37].

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